MICRO-ELECTRO-MECHANICAL MIRROR DEVICES HAVING A HIGH LINEAR MIRROR FILL FACTOR

Related Application

The present application is based on and claims priority from U.S. provisional patent application serial no. 60/311,657 filed on August 10, 2001 and entitled HIGH FILL FACTOR MEMS MIRRORS.

Field of the Invention

The present invention relates generally to micro-electromechanical (MEMS) devices and, more particularly, to MEMS devices having movable mirrors used, e.g., in optical switches, scanners and projectors.

Background of the Invention

Optical switches are used for routing optical signals in fiber optic networks. The switches selectively transmit light signals from a set of input fibers to a set of output fibers. The switches typically include at least one array of movable mirrors or reflectors that can be selectively actuated to deflect light signals to particular output fibers. The movable mirrors can be actuated or controlled in a variety of ways including through electro-magnetic actuation, electrostatic actuation, piezoelectric actuation, thermal bimorph and comb-drive actuation. Fabrication of the mirror arrays has been attempted using MEMS technology, in which silicon processing and related techniques common to the semiconductor industry are used to form micro-electromechanical devices.

Express Mail No. EL 703685405 US
Date of Deposit 2-28-02

Brief Summary of Embodiments of the Invention

Arrays of movable MEMS mirror devices are provided having a high linear mirror fill factor. In accordance with some embodiments, the arrays include a base structure and a plurality of selectively movable mirror structures pivotally mounted on the base structure. Each mirror structure is pivotally supported by a flexure connected to the base structure. The mirror structures each include a reflective surface portion, which is arranged in close proximity to the reflective surface portions of other mirror structures and in a generally linear alignment, forming a row structure. The flexures supporting adjacent mirror structures are staggered on opposite sides of the row structure. The array can have a linear mirror fill factor greater than about 70%.

These and other features of the invention will become readily apparent from the following detailed description wherein embodiments of the invention are shown and described by way of illustration of the best mode of the invention. As will be realized, the invention is capable of other and different embodiments and its several details may be capable of modifications in various respects, all without departing from the invention. Accordingly, the drawings and description are to be regarded as illustrative in nature and not in a limiting sense with the scope of the application being indicated in the claims.

Brief Description of the Drawings

For a fuller understanding of the nature and objects of the present invention, reference should be made to the following detailed description taken in connection with the accompanying drawings wherein:

FIGURE 1 is a schematic diagram illustrating the operation of a wavelength selective switch;

FIGURE 2 is a schematic diagram illustrating operation of the FIGURE 1 switch in greater detail;

FIGURE 3 is a schematic plan view diagram of a mirror array not optimized for linear mirror fill factor;

FIGURE 4 is a schematic plan view diagram of a mirror array in accordance with one embodiment of the invention; and

FIGURE 5 is a schematic plan view diagram of a mirror array in accordance with another embodiment of the invention.

Detailed Description of Preferred Embodiments

FIGURE 1 schematically illustrates the operation of a particular type of optical switch known as a wavelength selective cross connect switch, which can be used to switch optical signals between multiple input fibers or channels 10 and output fibers or channels 12. In particular, the switch allows a signal of any wavelength on any fiber to be switched to any output fiber. For example, in the 4x4 wavelength cross connect switch shown in FIGURE 1, each input wavelength (indicated by λ1 to λ40) can be switched to any one of four possible output fibers. In this illustration, there are 40 wavelengths per fiber or a total of 160 possible wavelength inputs. Other numbers of wavelengths per fiber are also possible such as, e.g., 80 or more wavelengths per fiber.

The 4x4 MEMS wavelength selective switch can use movable MEMS mirrors to selectively deflect signals between fibers. The mirrors are typically rotatable about a single axis, although rotation about two axes is also possible. Two MEMS mirror arrays 16, 18 are used as shown in FIGURE 2, which schematically illustrates an example of how MEMS mirror arrays are used in the switch. For ease of illustration, the figure only shows the path of one of the optical wavelengths (indicated by solid line 20). In this illustration, the mirrors are only rotatable about a single axis. As shown, an input wavelength (λ1) from fiber 1 is passed through an input diffraction grating 22 and onto the first mirror of the first mirror array 16, which directs the beam to the first mirror of a second set of mirrors 18. The mirror of the second set of mirrors 18 selectively directs the light to an output diffraction grating or lens 24, which combines signals of various wavelengths into the corresponding output fiber 12. The dashed lines 26 indicate other possible paths of the signal from the second set of mirrors 18.

Wavelength selective switches can also include only a single set of MEMS mirrors for deflecting light from input to output fibers. This is particularly

suitable for a 1XN or NX1 type switch.

It is desirable to have MEMS mirror arrays with a high linear mirror fill factor to increase the mirror surface coverage of the arrays and thereby reduce optical loss and improve performance. FIGURE 3 shows an example of a mirror array that is not optimized for linear mirror fill factor. The array of FIGURE 3 includes three selectively movable mirror devices 40 or "pixels". Each pixel includes a mirror structure 42 pivotally mounted on a flexure 44 connected to a base or support frame structure 46. Each mirror structure 42 includes first and second enlarged portions 48, 50 connected by a narrowed neck member 52. The neck member 52 is mounted on the flexure 44. The first enlarged portion 48 of the mirror structure includes a reflective mirror surface 54 for use in deflecting optical signals. The second enlarged portion 50 of the mirror structure typically includes an actuation device (such as, e.g., an electromagnetic actuation coil) for causing selective pivoting of the mirror structure about the flexure. A portion of the mechanical support frame 46 is located between adjacent mirror structures 42. This support frame is needed to support the flexures 44 and enable the mirror structures 42 to move independently of each other. The presence of the support structure 46, however, reduces the linear mirror fill factor of the array, which can be defined by the width of each mirror (indicated by WM) relative to the pixel pitch, which is the repeating distance between adjacent pixels (indicated by P).

The present invention is directed to MEMS mirror arrays having high linear mirror fill factors. Such arrays are useful for devices as shown in FIGURES 1 and 2. The linear mirror fill factor of the mirror array shown in FIGURE 3 can be improved as discussed below.

An example of a MEMS mirror array in accordance with a preferred

embodiment of the invention is shown in FIGURE 4. The array includes a base support structure 100 and a plurality of selectively movable mirror structures 102 pivotally mounted on the base structure 100. Each mirror structure 102 is pivotally supported by a flexure 104 connected to the base structure 100. The mirror structures 102 each include two enlarged portions 106, 108 separated by a neck member 110. One enlarged portion 106 includes an exposed reflective surface portion 112, which is arranged in close proximity to the reflective surface portions 112 of other mirror structures 102 in a generally linear alignment, forming a row structure. The other enlarged portion 108 of each mirror structure 102 can include an actuation mechanism (such as, e.g., an actuation coil for electromagnetically actuated devices) for causing desired selective movement of the mirror structure about the flexure.

Alternatively, both enlarged portions 106 and 108 can have actuation coils. The enlarged portion 106 includes an exposed reflective surface, which either covers or is adjacent to the coil on the enlarged portion 106.

As shown, mirror structures 102 are offset from one another in one of the two dimensions of the surface of the substrate on or in which the devices are built. The flexures 104 supporting adjacent mirror structures 102 are accordingly staggered on opposite sides of the row structure. As shown, the flexures can be buried in, i.e., extend into, the neck portion 110 of the mirror structure.

The base support structure 100 includes fingers or peninsulas or support members 114 of bulk substrate material extending to the flexures 104. The base support structure 100 preferably has the thickness of the wafer from which it is fabricated, and accordingly it is generally sufficiently thick so as to not act as a sensitive accelerometer.

The mirror structures 102 can also have other possible shapes. For example, the mirror structures can have a generally constant width (i.e., without any narrowed neck portion). With such a mirror structure, the fingers 114 of the base structure 100 can be narrowed to allow for increased flexure length if needed.

The spacing between the reflective surface portions or mirrors 112 in the FIGURE 4 array can be made very small. In the non-optimized device of FIGURE 3, the spacing between adjacent mirrors is about 190 microns for 400 microns wide mirrors. The pixel pitch ("P" defined as the repeating distance of the pixel) is accordingly 590 microns, which results in a linear fill factor of approximately 67% for the pixel. By contrast, for pixels in the FIGURE 4 array, the spacing between adjacent mirrors 112 can be as little as between 5 to 40 microns (or less) with the same mirror width (WM) of 400 microns. For an example 20 micron spacing, this results in the pixel pitch being 420 microns, with a linear fill factor of approximately 95%. Other spacings are also possible such that the linear fill factor is at least about 70%. The fill factor is preferably greater than 80%, and even more preferably greater than 90%.

Advantages of an increased linear mirror fill factor include greater mirror surface coverage and reduced optical loss in the same linear space. Switch performance is thereby improved.

FIGURE 5 illustrates a mirror array in accordance with another embodiment of the invention. The FIGURE 5 array includes differently sized mirrors. For example, the mirror array can include mirror structures 150, 152 having different widths. For such a mirror array, a linear mirror fill factor value can be determined for each pixel. This value is defined by WM/WP, where WM is the mirror width and WP is the pixel width (or mirror width plus half the

spacing on each side to adjacent mirrors). For each pixel in the array, the mirror fill factor can be greater than about 70%. The fill factor is preferably greater than about 80%, and more preferably greater than about 90%.

Mirror arrays in accordance with the invention may be used with a variety of mirror actuation mechanisms including, e.g., electromagnetic, electrostatic, thermal, piezoelectric, and other forms of mirror actuation.

High fill factor mirror arrays in accordance with the invention can be used in a switching device having any number of optical fibers. Also, the number of input and output fibers can be different, i.e., the number of input fibers can be greater than or less than the number of output fibers. In addition, use of a single mirror array or multiple mirror arrays is possible.

A variety of different flexures can be used for pivotally supporting mirror structures in the arrays. For example, use of folded flexures is possible. Additionally, the flexures may have various cross-sectional shapes including, e.g., a generally non-rectangular cross-sectional shape such as a generally "U" or "V" cross-sectional shapes.

In addition, the flexures can be thinned or sized appropriately to allow at least a small movement of the mirror orthogonal to the main axis of rotation. Accompanying actuators can be implemented to provide motion control on both axes. Such actuators can include, e.g., split electrode electrostatic actuators.

High linear fill factor mirror arrays in accordance with the invention can be used in a variety of devices including optical switching devices (such as, e.g., wavelength selective switches), scanning devices and projectors. In addition, high linear fill factor arrays of other MEMS actuators are also possible.

Having described various preferred embodiments of the present invention, it should be apparent that modifications can be made without departing from the spirit and scope of the invention.